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Lung ultrasonography underdiagnoses clinically significant pneumothorax

Jarrett E. Santorelli, MD*, Aaron Marshall, MD, Louis Perkins, MD, Laura Adams, MD, Lisa Kurth, MD, Jay J. Doucet, MD, Todd W. Costantini, MD

Division of Trauma, Surgical Critical Care, Burns and Acute Care Surgery, Department of Surgery, UC San Diego School of Medicine, San Diego, CA

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ABSTRACT

Background: Ultrasonography for trauma is an integral part of the Advanced Trauma Life Support algorithm and supported extensively in the literature. The reliability of chest ultrasonography as a screening examination for pneumothorax during initial trauma evaluation is unclear. We performed a prospective study where we hypothesized that chest ultrasonography would have low sensitivity for detecting clinically significant pneumothorax.

Methods: A prospective observational analysis of patients with blunt chest trauma at a level 1 trauma center was performed. Patients included had supine chest radiography and chest ultrasonography performed prior to intervention as well as confirmatory computed tomographic imaging. All chest ultrasonography was performed in the trauma bay by a registered sonographer. All imaging was evaluated by an attending trauma surgeon and radiologist in real time.

Results: Of 2,185 patients screened with a diagnosis of blunt thoracic trauma, 1,489 patients had chest radiography, chest ultrasonography, and confirmatory computed tomography and were included for analysis. Patients were 71% male, with median age of 42 years, and mean Injury Severity Score of 6. The sensitivity of chest ultrasonography to detect pneumothorax was low. Chest ultrasonography had a false negative rate of 72% (n = 58), with 22% (n = 13) undergoing tube thoracostomy. Patients with false negative examinations had lower initial O_2 saturation and systolic blood pressure and were more likely to have rib fractures compared with true negative chest ultrasonography examinations.

Conclusion: Chest ultrasonography performed on initial trauma evaluation has low sensitivity with a high rate of false negative examinations. Because many of these false negative results are clinically significant requiring thoracostomy, using chest ultrasonography alone to screen for pneumothorax should be done with caution.

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Background

Up to half of all patients who sustain chest wall trauma present with pneumothorax (PTX), a well-understood yet complicated injury that requires accurate diagnosis and prompt management.[1–3] Although computed tomography (CT) remains the gold standard for diagnosis of traumatic PTX, other diagnostic modalities, including supine chest radiograph (CXR) and ultrasonography, are often obtained during the initial resuscitation of the injured patient to rapidly confirm or exclude the presence of PTX.[4] Despite its documented low sensitivity (36%–48%), CXR is still regarded as the primary screening tool for PTX in the 10th edition Advanced Trauma Life Support (ATLS) Course.[5,6] Alternatively, the applications for ultrasonography in trauma have significantly increased in the last 3 decades, and in multiple recent studies, its sensitivity and specificity for the detection of PTX has been shown to rival, if not surpass, the diagnostic capabilities of CXR.[7,8]

Our facility has liberally used the complete ultrasonography of trauma (CUST) examination since its inception, which produces high-quality sonographic images of the thoracic and abdominal cavities to rule out clinically significant pathology, including traumatic PTX.[9] Although relying solely on ultrasonography for the

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* Corresponding author: Jarrett E. Santorelli, MD, Division of Trauma, Surgical Critical Care, Burns and Acute Care Surgery, Department of Surgery, UC San Diego School of Medicine, 200 West Arbor Drive, San Diego, CA 92103.
E-mail address: Jsantorelli@health.ucsd.edu (J.E. Santorelli);
Twitter: @JE_Santorelli

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detection of PTX has not been universally accepted as the standard of care, there are data to suggest that ultrasonography may be superior to CXR in the detection of PTX.[6,10,11] We recently performed a retrospective analysis of trauma patients that questioned the reliability of thoracic ultrasonography as a single screening modality for PTX, demonstrating that lung ultrasonography (LUS) had markedly worse sensitivity and missed a higher percentage of clinically significant PTX compared with CXR.[12]

The utility of LUS in the detection of PTX during the initial trauma evaluation is controversial, with a paucity of prospective data comparing these 2 imaging modalities as a screening tool for PTX. Recently multiple studies have touted superior sensitivity for LUS (up to 99%).[13–16] The majority of these studies are performed in the emergency department, on mixed patient populations, with small sample sizes, and not performed as a screening examination on sequential patients, which could possibly introduce selection bias. Given the lack of adequate data in support of LUS as a screening tool for PTX, it is unclear why there is a general acceptance of its superiority. This notion and vague data are reflected in the 2022 Western Trauma Association critical decision algorithm recommending the use of CXR over ultrasonography for monitoring PTX size.[4,13–16] The aim for this study was to better understand the reliability of LUS alone as a screening tool for PTX during the initial trauma resuscitation in a prospective fashion. We hypothesized that CXR would demonstrate superior sensitivity for the detection of traumatic PTX when compared to LUS.

Methods

We performed a prospectively collected, retrospective observational cohort study of patients with chest wall trauma at a level 1 trauma center from February to December 2022. Patients were screened and assessed for study inclusion within 1 hour of presentation to our facility. Only patients who underwent routine supine CXR and LUS prior to any intervention as well as confirmatory computed tomography (CT) imaging were included. Patients were excluded if they did not undergo CXR or LUS on arrival or if they required emergent tube thoracostomy before any imaging was obtained (Figure). Data was deidentified for analysis. Institutional review board approval was obtained, and because of the observational nature of this study, a waiver of informed consent was granted. The STROBE guidelines were applied for proper reporting of the results of this study (see Supplementary Material).

LUS was performed during the complete ultrasonography of trauma (CUST) assessment, which is performed during all trauma resuscitations at our center. The CUST examination includes the 4 standard eFAST views (right upper quadrant, left upper quadrant, pelvic, and pericardial windows) in addition to epigastric, retroperitoneal, and bilateral paracolic gutter windows. Additionally, 4 thoracic views are obtained in each hemithorax (2 anterior and 2 lateral views at different intercostal spaces). These examinations were performed by American Registry of Diagnostic Medical Sonography–registered sonographers. During the chest portion of the examination, a high-frequency (8.5–10 MHz) linear array (9L-D) probe on lung settings with autoscan turned off and depth set based on body habitus (ATL HDI 3000 [Advanced Technologies Laboratories, Bothell, WA] or Acuson Model 128-XP [Siemens Medical Solutions USA, Inc, Malvern, PA]) using a protocol previously described by our institution.[9] The CUST examination is observed and interpreted first at the bedside by the trauma team, noting any concerning findings to suggest PTX, such as absence of normal lung sliding ("sliding sign"). If PTX is suspected, we assess for a "barcode" or "stratosphere" sign using the motion modality (M-mode) on the ultrasonography machine. Both B and M mode are used during all scans, and all images are stored for quality review and saved as video loops so as to prevent interobserver bias. At the conclusion of the examination, the sonographer immediately uploads all imaging for review by an attending radiologist for preliminary and final interpretation in real time. Thoracostomy tube placement is at the discretion of the attending trauma surgeon. Institutional guidelines recommend observation when radial measurement is <30 mm in an otherwise stable patient as described by de Moya et al.[4]

Additional variables collected were patient demographics (age, sex, body mass index), admission blood pressure, admission heart rate, Injury Severity Score, and mechanism of injury. Occult PTXs were defined as those too small for measurement on CT (typically <2 mm) or by a radiologist's indication of "trace" on the final CT reading.

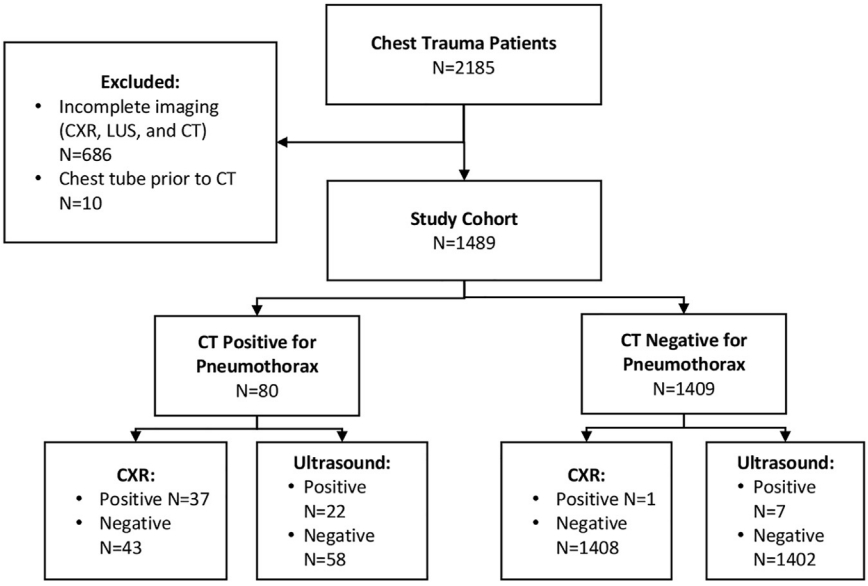

Figure. Patient selection criteria. A schematic of the patients included and excluded in this study from the entire population (n = 2,185).

Statistical analysis was performed using R Studio (R version 4.3.0; Posit, Boston, MA). Categorical variables were compared using Pearson χ^2 or Fisher exact test when appropriate, and continuous variables were compared using the Mann-Whitney *U* test. Data for continuous variables are reported as median and first-third interquartile. All tests were 2-sided. Power analysis prior to study initiation was conducted, and based on prior literature, to achieve a power of 80% for sensitivity and specificity, a sample size of 1,297 patients was needed.

Results

There were 2,185 patients identified with the diagnosis of thoracic trauma during the study period. After excluding patients who did not undergo necessary diagnostic imaging or had emergent thoracostomy placement, 1,489 patients were included for analysis (Table I). Of these, there were 80 patients (5.3%) who presented with PTX as confirmed by admission CT imaging. The entire cohort was predominantly male (71.4%), with median age of 42 years (29–62). Patients sustained predominantly blunt chest wall trauma (96.4%) with a median Injury Severity Score of 6 (5–10).

The sensitivity and specificity for detection of PTX were compared between the 2 modalities for all included patients (Table II). LUS and CXR both exhibited very high specificity, but CXR demonstrated superior sensitivity when compared to LUS (46.3% vs 27.5%). LUS had a false negative rate of 72% (n = 58); of these, 22% (n = 13) had clinically significant PTX that required tube thoracostomy. Comparatively, CXR demonstrated a false negative rate of 53% (n = 43); 20% (n = 9) of these patients required tube thoracostomy.

To compare each screening test's ability to detect clinically significant PTX, all occult PTXs were removed from each group, and the sensitivity of both tests improved. CXR remained superior to LUS (62.2% vs 46.7%, $P = .016$) (Table III). False negative and true positive LUS results were compared; the median size of PTX was significantly smaller in the false negative group (13 mm vs 25 mm, $P = .01$) (Table IV). Similarly, when comparing false negative and true positive CXR results, the median size of PTX was significantly smaller in the false negative group (12 mm vs 27 mm, $P < 0.01$) (Table V). Finally, when using these tests in conjunction, we observed the combined sensitivity and specificity, if either test is positive, to significantly increase to 71.1% and 99.4%, respectively.

Table I
Demographics of patients screened by lung ultrasonography ($N = 1,489$)

Variable	Value
Age, y, median (IQR)	42 (29–62)
Male sex, *n* (%)	1,060 (71.2)
BMI, median (IQR)	27 (23–31)
SBP, mm Hg, median (IQR)	135 (120–150)
Heart rate, bpm, median (IQR)	88 (77–101)
ISS, median (IQR)	6 (5–10)
Chest AIS score, *n* (%)	
0	1,212 (81.4)
1–2	129 (8.7)
3–4	143 (9.6)
5	5 (0.3)
Mechanism of injury, *n* (%)	
Blunt	1,435 (96.4)
Penetrating	54 (3.6)

AIS, Abbreviated Injury Score; *BMI*, body mass index; *IQR*, interquartile range; *ISS*, Injury Severity Score; *SBP*, systolic blood pressure.

Table II
Imaging modality confusion matrix (including occult pneumothoraces)

	CT positive ($n = 80$)	CT negative ($n = 1409$)	
LUS			
Positive (n = 29)	22	7	Sensitivity 27.5%
Negative (n = 1,460)	58	1,402	Specificity 99.5%
	PPV 75.9%	NPV 96.0%	
Chest radiograph			
Positive (n = 38)	37	1	Sensitivity 46.3%
Negative (n = 1,451)	43	1,408	Specificity 99.9%
	PPV 97.4%	NPV 97.0%	

CT, Computed tomography; *LUS*, lung ultrasonography; *NPV*, negative predictive value; *PPV*, positive predictive value.

Table III
Imaging modality confusion matrix (excluding occult pneumothoraces)*

	CT positive ($n = 45$)	CT negative ($n = 1,444$)	
LUS			
Positive (n = 28)	21	7	Sensitivity 46.7%
Negative (n = 1,461)	24	1,437	Specificity 99.5%
	PPV 75.0%	NPV 98.4%	
Chest radiograph			
Positive (n = 29)	28	1	Sensitivity 62.2%
Negative (n = 1,460)	17	1,443	Specificity 99.9%
	PPV 96.5%	NPV 98.8%	

CT, Computed tomography; *LUS*, lung ultrasonography; *NPV*, negative predictive value; *PPV*, positive predictive value.
* Analysis conducted by treating occult pneumothoraces as a negative finding on CT result.

Discussion

As the applications for ultrasonography in the acute trauma patient continue to grow, there remains controversy about its ability to replace CXR as the initial screening examination for PTX. Affirming the results of our recent retrospective analysis, our study is the most recent to provide prospective data that show CXR to be a more reliable modality during the initial workup of trauma patients. The false negative rate for LUS is significantly higher than that of supine CXR, suggesting that its utility as a screening tool for PTX is more limited than previously believed. With the overall low sensitivity observed in both examinations, similar to a previous study by Moore et al, we believe relying solely on either examination should be done with caution as both have significant limitations.[17]

There are a few prospective comparisons of CXR and LUS for the detection of PTX, though methodologically, our study is comparable to the 2005 study by Blaivas et al,[18] which demonstrated markedly better sensitivity of LUS compared with CXR (98% vs 76%, respectively). The majority of false negative LUS examinations in our study were in instances of small or trace PTXs, yet Blaivas et al were able to diagnose even the smallest of PTXs with very high sensitivity, a perplexing result given the nearly 2 decades of technological advancement in ultrasonography that has occurred since

Table IV
Comparison of patients with false negative and positive LUS examinations with CT-confirmed clinically significant pneumothorax*

	False negative LUS ($n = 24$)	True positive LUS ($n = 21$)	*P* value
Age, y, median (IQR)	48 (30–59)	34 (26–63)	.400
Sex, male/female, *n*	16/8	18/3	.177
BMI, median (IQR)	26 (21–31)	26 (22–30)	.920
SBP, mm Hg, median (IQR)	136 (110–146)	122 (110–147)	.973
Heart rate, bpm, median (IQR)	90 (70–110)	101 (88–108)	.232
ISS, median (IQR)	14 (12–22)	14 (10–27)	.706
Mechanism of injury, *n*			.040†
Blunt	24	17	
Penetrating	0	4	
PTX size, mm, median (IQR)	13 (9–20)	25 (17–55)	.011†
Thoracostomy, *n* (%)	8 (33)	15 (71)	.017†

BMI, Body mass index; *CT*, computed tomography; *IQR*, interquartile range; *ISS*, Injury Severity Score; *LUS*, lung ultrasonography; *PTX*, pneumothorax; *SBP*, systolic blood pressure.
* Excludes occult pneumothoraces ($n = 35$).
† Significant at alpha value of .05.

Table V
Comparison of patients with false negative and positive CXR examinations with CT-confirmed clinically significant pneumothorax*

	False negative CXR ($n = 17$)	True positive CXR ($n = 28$)	*P* value
Age, y, median (IQR)	46 (25–64)	38 (29–59)	.925
Sex, male/female, *n*	12/5	22/6	.722
SBP, mm Hg, median (IQR)	132 (118–140)	133 (110–148)	.953
Heart rate, bpm, median (IQR)	91 (81–106)	101 (84–108)	.566
BMI, median (IQR)	26 (23–28)	25 (22–30)	.913
ISS, median (IQR)	13 (9–14)	17 (14–28)	.039†
Mechanism of injury, *n*			.281
Blunt	17	24	
Penetrating	0	4	
PTX size, mm, median (IQR)	12 (7–13)	27 (18–45)	<.001†
Thoracostomy, *n* (%)	4 (24)	19 (68)	.006†

BMI, Body mass index; *ISS*, Injury Severity Score; *PTX*, pneumothorax; *SBP*, systolic blood pressure.
* Excludes occult pneumothoraces ($n = 35$).
† Significant at alpha value of .05.

publishing their findings. There are several notable differences between these studies. First, there were considerably fewer eligible patients enrolled in their study (176) vs ours (1,499), suggesting that our results may be more reflective of the true sensitivity of LUS. Next, emergency department personnel performed LUS in the Blaivas et al study with preferential enrollment of eligible patients depending on the availability of LUS-proficient providers, thus introducing selection bias. The measure for proficiency in LUS in Blaivas et al was markedly different from ours, as the emergency department personnel were required to perform only 10 thoracic ultrasonographs before independently performing LUS and enrolling patients. This contrasts with our center's experience, which deploys registered sonographers for thousands of trauma activations annually. Additionally, the interpretation of the CXR results by Blaivas et al was performed in real time by the emergency department personnel without any additional corroboration of positive and negative findings by an attending radiologist, a limitation that the authors acknowledge in their manuscript. As such, the sensitivity of CXR is almost certainly underestimated by omitting final interpretation. Finally, although our study used CT confirmation of PTX as the gold standard of diagnosis, Blaivas et al equated a “rush of air” during chest tube placement to a positive CT result, which is a subjective diagnostic tool in this regard. The authors of that study do not specifically state how many of the 53 total PTXs were confirmed solely by CT; so when comparing the results of these 2 studies, this must be taken into consideration.

Reduced radiation exposure, cost reduction, and real-time results make ultrasonography an important tool in the evaluation of injured patients, although our data largely contradicts previously reported sensitivity of LUS for the diagnosis of PTX. Two meta-analyses by Alrajab et al[19] and Ebrahimi et al[20] demonstrated sensitivities of LUS ranging from 79% to 87%, far surpassing the 40% to 46% sensitivity reported for CXR. Although both reviews included dated studies in nonhomogenous and nontraumatic patient populations, both acknowledge the operator-dependent nature of LUS examinations. A more recent meta-analysis of 12 prospective studies over a 20-year period by Tian et al[21] evaluating detection of PTX via LUS demonstrated a combined pooled sensitivity of nearly 90%, markedly higher than what we report in this study. Our institution has relied on registered sonographers to perform the CUST examinations because we universally implemented it in trauma activations, and this consistency leads us to conclude that the sensitivity of LUS in this study is a rigorous and accurate assessment of the true sensitivity of LUS for the diagnosis of PTX.[9,12]

For both modalities, it would be clinically beneficial to identify patient populations that are at greatest risk for missed PTX. Like our center's prior retrospective analysis, most patient-specific factors, such as body mass index, gender, or severity of injury, did not accurately predict when an LUS study would be inaccurate. Our prior retrospective study did find that young patients were more likely to have a false negative LUS, although this was not observed in this prospective analysis. The false negative LUS results occurred

more frequently in blunt trauma patients (no penetrating-related PTXs were missed in this group), but it is unclear how to interpret this finding or how it would impact patient care. Similarly, there were no discernable or clinically relevant differences between the true positive and false negative CXR results. The size of the PTX is the unifying theme for both modalities: smaller PTXs are at greater risk of being missed during the initial trauma assessment. As such, it is extremely important for clinicians to maintain a high index of suspicion for PTX based on mechanism or hemodynamic status in the setting of negative CXR or LUS. It may be useful to use these tests in conjunction as we observed the combined sensitivity and specificity, if either test is positive, to significantly increase to 71.1% and 99.4%, respectively.

Study limitations

Our study has several limitations. First, although prospective in nature, it is still a single-institution study with a relatively low sample size of PTX and short enrollment period, so detection of subtle yet significant differences between LUS and CXR modalities is challenging. Next, our center uses licensed sonographers to obtain LUS images; we feel strongly that use of these technicians increases the detection rate of subtle PTXs during the CUST assessment, but it remains unclear how this impacts the generalizability of our findings, as most institutions rely on emergency medicine or trauma surgery personnel to perform the ultrasonography assessment. Finally, because we excluded patients who did not undergo all imaging or had emergent thoracostomy tube placement, the largest PTXs may have been excluded, decreasing the sensitivity of both LUS and CXR.

In conclusion, in this prospective analysis, LUS demonstrated inferior sensitivity for the detection of traumatic PTX when compared to traditional supine CXR as a screening examination on all trauma patients, challenging recent studies that assert the superiority of LUS for this purpose. We recommend continuing to use CXR as well as ultrasonography as adjuncts in the ATLS primary survey as their combined sensitivity is superior to either examination individually. We additionally recommend caution if relying on sonography alone as a screening tool for the detection of traumatic PTX.

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Conflict of Interest/Disclosure

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CRediT authorship contribution statement

Jarrett E. Santorelli: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aaron Marshall:** Writing – review & editing, Writing – original draft, Formal analysis. **Louis Perkins:** Writing – review & editing, Formal analysis. **Laura Adams:** Writing – review & editing, Data curation. **Lisa Kurth:** Writing – review & editing, Data curation. **Jay J. Doucet:** Writing – review & editing. **Todd W. Costantini:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Supplementary material

Supplementary materials associated with this article can be found in the online version, at [https://doi.org/10.1016/j.surg.2024.08.013].

References

1. Sharma A, Jindal P. Principles of diagnosis and management of traumatic pneumothorax. *J Emerg Trauma Shock*. 2008;1:34–41.
2. Marro A, Chan V, Haas B, Ditkofsky N. Blunt chest trauma: classification and management. *Emerg Radiol*. 2019;26:557–566.
3. Tran J, Haussner W, Shah K. Traumatic pneumothorax: a review of current diagnostic practices and evolving management. *J Emerg Med*. 2021;61:517–528.
4. de Moya M, Brasel KJ, Brown CVR, et al. Evaluation and management of traumatic pneumothorax: a Western Trauma Association critical decisions algorithm. *J Trauma Acute Care Surg*. 2022;92:103.
5. *ATLS: Advanced Trauma Life Support*. 10th ed. American College of Surgeons; 2018.
6. Abdulrahman Y, Musthafa S, Hakim SY, et al. Utility of extended FAST in blunt chest trauma: is it the time to be used in the ATLS algorithm? *World J Surg*. 2015;39:172–178.
7. Chan KK, Joo DA, McRae AD, et al. Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department. *Cochrane Database Syst Rev*. 2020;7:CD013031.
8. Staub LJ, Biscaro RRM, Kaszubowski E, Maurici R. Chest ultrasonography for the emergency diagnosis of traumatic pneumothorax and haemothorax: a systematic review and meta-analysis. *Injury*. 2018;49:457–466.
9. Dehqanzada ZA, Meisinger Q, Doucet J, Smith A, Casola G, Coimbra R. Complete ultrasonography of trauma in screening blunt abdominal trauma patients is equivalent to computed tomographic scanning while reducing radiation exposure and cost. *J Trauma Acute Care Surg*. 2015;79:199–205.
10. Dulchavsky SA, Schwarz KL, Kirkpatrick AW, et al. Prospective evaluation of thoracic ultrasound in the detection of pneumothorax. *J Trauma*. 2001;50:201–205.
11. Wilkerson RG, Stone MB. Sensitivity of bedside ultrasound and supine anteroposterior chest radiographs for the identification of pneumothorax after blunt trauma. *Acad Emerg Med*. 2010;17:11–17.
12. Santorelli JE, Chau H, Godat L, Casola G, Doucet JJ, Costantini TW. Not so FAST-Chest ultrasound underdiagnoses traumatic pneumothorax. *J Trauma Acute Care Surg*. 2022;92:44–48.
13. Osterwalder J, Seibel A. Not so FAST replacing the "e" in e-FAST with supine chest-x-ray. *J Trauma Acute Care Surg*. 2022;93:e40.
14. Torri E, Zanforlin A, Soldati G, et al. Not so FAST but not so furious: an improper method underdiagnoses pneumothorax-answer to the article "Not so FAST-chest ultrasound underdiagnoses traumatic pneumothorax.". *J Trauma Acute Care Surg*. 2022;93:e186–e187.
15. Volpicelli G, Lamorte A. Technique and timing may influence sensitivity of lung ultrasound for pneumothorax in trauma patients. *J Trauma Acute Care Surg*. 2022;93:e41–e43.
16. Kim DJ, Theyyunni N, Liu RB. Ultrasound is superior to supine chest x-ray for the diagnosis of clinically relevant traumatic pneumothorax. *J Trauma Acute Care Surg*. 2022;93:e43–e44.
17. Moore C, Wilson B, Oury J, et al. Chest X-ray remains a vital component prior to tube thoracostomy. *Am Surg*. 2024;90:23–27.
18. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Acad Emerg Med*. 2005;12:844–849.
19. Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care Lond Engl*. 2013;17:R208.
20. Ebrahimi A, Yousefifard M, Mohammad Kazemi H, et al. Diagnostic accuracy of chest ultrasonography versus chest radiography for identification of pneumothorax: a systematic review and meta-analysis. *Tanaffos*. 2014;13:29–40.
21. Tian H, Zhang T, Zhou Y, Rastogi S, Choudhury R, Iqbal J. Role of emergency chest ultrasound in traumatic pneumothorax. An updated meta-analysis. *Med Ultrason*. 2023;25:66–71.